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"COMPARISON OF DIFFERENT HEURISTIC METHODS FOR ASSEMBLY LINE BALANCING - A REVIEW "

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ABSTRACT

In a production system, line balancing is a very essential part for smooth production, but balancing a line is very difficult even if it is a simple assembly line. So, to solve these problems heuristic methods are very much useful. There are number of heuristic methods are available, therefore it become very much important to use more efficient heuristic method. In this paper we present a comparison of different heuristic methods based on cycle time, idle time, line efficiency, smoothness index, production rate. This review paper is concern with the objective of using a heuristic method which minimize number of work station and increase line efficiency.

KEYWORDS : *Heuristic methods, Assembly line balancing problem, SALB.*

I. INTRODUCTION

An assembly line is a manufacturing process in which interchangeable parts are added as the semi-finished assembly, moves from one work station to other work station where the parts are added in a sequence up to the final assembly [1].

For any production system any assembly line consists of set of workstation arranged in one particular fashion interlinking each other with material handling device. It can be linear, circular, u shaped, ladder etc. The movement of material via assembly line begins with part or material fed at initial point with particular feed rate [2]. Assembly lines are classified according to the number of models and products that are treated. They are divided into groups according to the way they are produced. Assembly line balancing methods are separated into three groups according to the solution approach: single model, multi-model and mixed-model assembly lines [3-5].

Assembly line balancing method based solution approaches are threefold: Heuristic methods, analytical methods and simulation techniques [6]. In literature the objective usually is to minimize the number of stations in a line for a "fixed cycle time (1, p. 650). In other words: The objective is to minimize the total idle time of the total capacity provided by the sum of the stations of the line (2, p. 911). Therefore, this is called time-oriented assembly line balancing [4]. An assembly line balancing (ALB) problem is well-known in industry. An assembly line is specified by a finite set of tasks, processing time for each task and the precedence relationship which defines permissible ordering of tasks. The ALB problem involves assigning assembly tasks to workstations to optimize individual objectives without violating the precedence relationships. Important are ALB problems, cost reduction and an output rate increase by minimizing cycle time, lack of time or number of workstations. Because the ALB problem is a combinatorial optimization problem, the time needed to solve a problem increases progressively with the size of the problem, which makes large problems impossible to solve. Approximation algorithms were developed to obtain near-optimal solutions. Heuristic procedures for solving the ALB problem are the most widely studied and discussed in the literature. Although the ALB problem has been studied for decades, new approximation algorithms are present in recent publications [10-15]. The meta- heuristic procedures, e.g., genetic algorithms, are also efficient at finding solutions to bigger ALB problems [31-34]. Some ALB researchers developed mathematical models of dedicated and mixed models of ALB problems and applied optimization techniques like goal programming [35-36] and branch-and-bound procedure [17, 18]{37-38} to solve the problems.

II. ASSEMBLY LINES

Mass production allows a lower cost production due to the large amount of produced units of the same product, and it is only possible by the division of labour [16

The great production increase resulting from the division of labour is due to three factors: increased dexterity of each worker; reduced wasted time when going from one type of work to another and the invention of a large number of machines that facilitate working, allowing one person to do the job of many [17].

The assembly line became popular with the mass production of automobiles, when Henry Ford began assembling the T model in the "Highland Plant “factory in 1913. In an assembly line system, the raw material enters and moves progressively through a series of workstations while being processed into the desired product [18]. The total amount of work in the assembly process is divided into elementary operations, called tasks, which require a time to be performed. The tasks follow precedence relationship, in such an order that, to accomplish a task, all its predecessors have to have already been executed [16], [19]. Kimms [20] states that, to ensure the full production of each model that passes through the line, each station must be equipped with machines, robots and trained people. The number of stations and station equipment is called line configuration. All of the work content of the assembly process is divided among the workstations, which repeat the operations at every certain time interval, called cycle time, without violating the assembly precedence relationships [16], [19], [20]. The problem of optimizing the division of tasks among workstations is known as Assembly Line Balancing Problem - ALBP [21].For Magatão et al. [22], Farnes and Pereira [23] and Falkenauer [24], the basic concept of line balancing is to either assign tasks to workstations in a line to get the desired index of production (or cycle time)with fewer workstations (employees), or to minimize the cycle time for a given number of employees. The number of stations or the time cycle is a performance measurement to be optimized.Regarding the number of products, the assembly lines can be classified into three basic types [19], [25]: Single-model assembly line: used in mass production of a single product, as in Figure 1a. Mixed-model assembly line: used to produce several models of a basic product, without the need to setup (or with a very little setup time). Figure 1b shows an example of this type of line. Multi model assembly line: used when there are significant differences in the production processes of each model. To minimize the inefficiency of the setup time between models, batches are used, and it originates the batch sizing problem. This line type is illustrated in Figure 1c

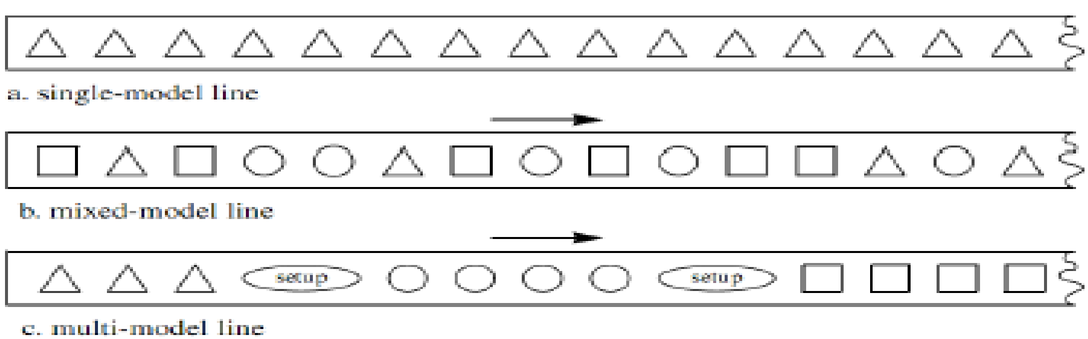

Fig1: Assembly line for single and multiple products

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2.1 Terminologies used in line balancing

(a) Cycle Time (Ct):- It the time for which job remains in a work station, or we can say that it is the time gap between two successive products coming out of the assembly line.

$$C_t \geq STmax$$

STmax is station max time.

Process duration = *Production time per day* / *Unit required per day*

(b) Workstation: It is a specific location on the assembly line where given amount of elemental task are performed by an operator.

(c) Precedence: The precedence graph is constructed to help visualize the predecessor tasks. The work elements are indicated by circles, with the time required to perform them under each circle. Arrows lead from the immediate predecessors to the next element of the work [26].

The mixed-model study began in 1970 with Thomopoulos [27]. For Gehardt [28], the most important contribution of Thomopoulos was the possibility of uniting the precedence diagrams for each model in an equivalent precedence graph, resulting in reduction in the work amount inequality along the line.

The union of the precedence graphs may be performed only if there are no conflicts of precedence between the models, for example, a model requires that task A is performed before task B, then no other model must request that task B be performed before A [29]. In Figure 2 two examples of precedence graphs are shown [28]. When constructing the equivalent precedence graph, the equivalent processing times are computed from the production rate of each model within a given time period (the sum of the production rates of all the models have to be equal to one). By multiplying the task execution time of each model by the percentage of the model demand and making the sum for each task, the equivalent time is obtained [30].

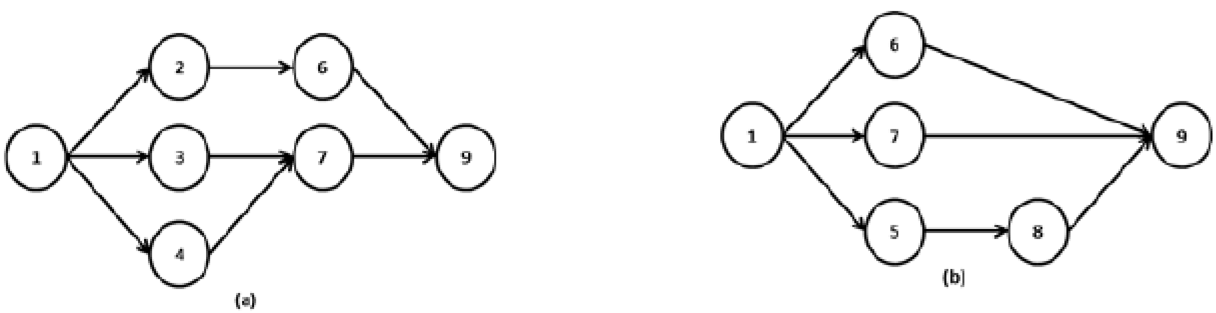

Fig 2.1: Precedence graph for (A) Model A and (B) Model B [16]

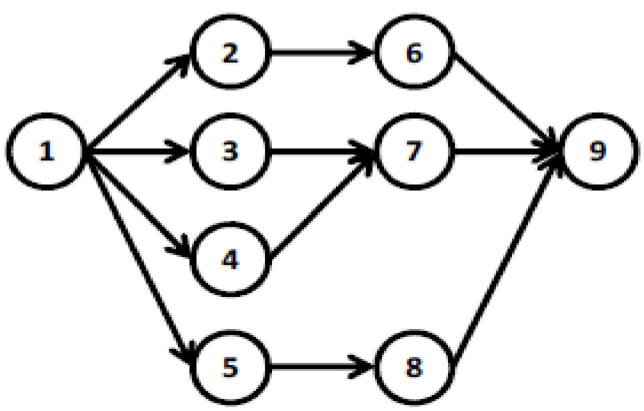

Fig 2.2: Equivalent precedence graph [16].

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(d) Lead Time: It is Summation of all the production times in an assembly line.

Lead Time = Σ Production Time along the assembly line

(e) **Idle Time**: Idle time can be defined as the time for which the system is not in use.

(f**) Number of Workstations**: (K) the number of stations composing the assembly line. The aim is to have the minimum number of workstations.

(g) **Productivity**: Productivity can be defined as the ratio of output over input. Productivity depends on various factors such as workers skills, methods of job and type of machine used.

Productivity = $Output\ /Labour\ *Production\ time\ pe\ r\ day\ (hour)$

(h) Bottleneck: It is defined as the delay in transmission due to which there is slow down in the production rate. This can be overcome by balancing the line.

(i) Smoothness File: It tells about the load distribution between different work stations compare to a station consuming maximum time.

$$SI=\sqrt{\sum_{i=1}^{k}(\,(STmax - STi)^{2}}$$

Where STmax = maximum station time
STi = Station time of station i

(j) Balance Delay: This is the ratio of total ideal time on the line to the total time spent by the job on the assembly line.

BD = $k * ct - (i\ kl = 1)/k * CT * 100\%$

(k) Line efficiency: Line Efficiency can be defined as the ratio of the total station time to the cycle time multiplied by the number of the work station, or, in other words it is the rate of total station time to the product of the cycle time and the number of work station. We can express this as

LE = $STi\ Mi = 1\ c * k$ X100 %

Where: k – total number of workstations, C– cycle time STi – station time [1]

III. CLASSIFICATION OF ALBP

(a) Ghosh and Gagnon (1989) [8] classified the ALBP into four categories; as shown in Figure 2

(1) Single Model Deterministic (SMD)
(2) Single Model stochastic (SMS)
(3) Multi/Mixed Model Deterministic (MMD)
(4) Multi/Mixed Model stochastic (MMS)

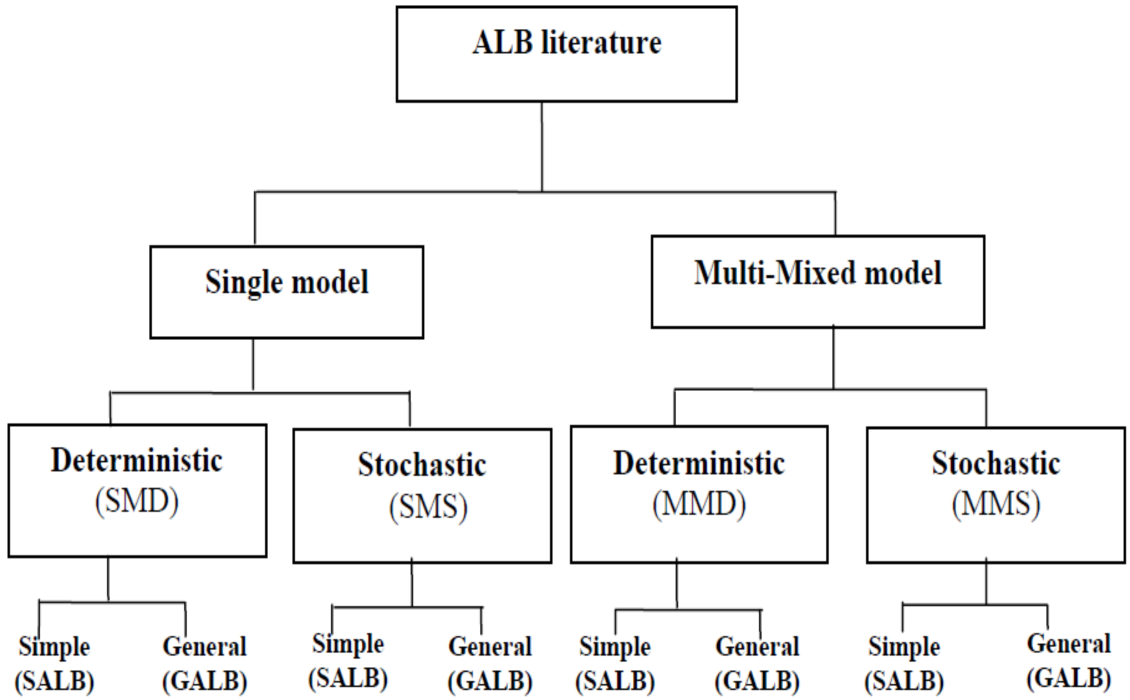

Fig 3.1: Classification of assembly line balancing literature (Ghosh and Gagnon, 1989)

The SMD version of the ALB problem assumes dedicated, single model assembly lines where the task times are known deterministically and an efficiency criterion is to be optimized. This is the original and simplest form of the assembly line balancing problem (SALB). Introduce other restrictions or factors (e.g. parallel stations, zoning restrictions) into the model and the problem becomes the General Assembly Line Balancing Problem (GALB)

The SMS problem category introduces the concept of task-time variability. This is more realistic for manual assembly lines, where workers' operation times are seldom constant. With the introduction of stochastic task times many other issues become relevant, such as station times exceeding the cycle time (and perhaps the production of defective or unfinished parts), pacing effects on workers' operation times, station lengths, the size and location of inventory buffers, launch rates and allocation of line imbalances.

The MMD problem formulation assumes deterministic task times, but introduces the concept of an assembly line producing multiple products. Multi-model lines assemble two or more products separately in batches. In mixed-model lines single units of different models can be introduced in any order or mix to the line.

Multi-mixed model lines introduce various issues that are not present in the single-model case. Model selection, model sequencing and launching rate(s) and model lot sizes become more critical issues here than in the single model case.

The MMS problem perspective differs from its MMD counterpart in that stochastic times are allowed. However, these issues become more complex for the MMS problem because factors such as learning effects, worker skill level, and job design and worker task time variability become more difficult to analyse because the line is frequently rebalanced for each model assembled.

(b) Scholl and Becker (2006); Becker and Scholl (2006) [8]

They have classified the main characteristics of assembly line balancing problems considered in their several constraints and different objectives as shown in Figure 3. It has illustrated the classification of assembly line balancing problems.

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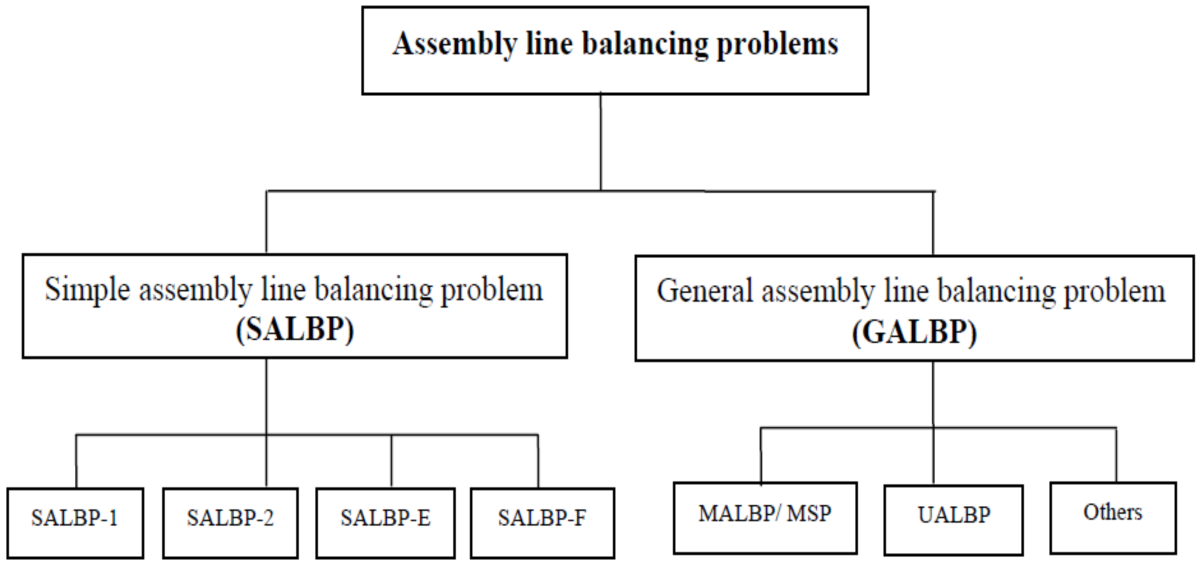

Fig 3.2: Classification of assembly line balancing problems

(1) SALBP: The simple assembly line balancing problem is relevant for straight single product assembly lines where only precedence constraints between tasks are considered (for a survey see Scholl and Becker, 2006)

- Type 1 (SALB-1) of this problem consists of assigning tasks to work stations such that the number of stations *(m)* is minimized for a given production rate (fixed cycle time, *c*).
- Type 2 (SALBP-2) is to minimize cycle time (maximize the production rate) for a given number of stations *(m).*
- Type E (SALBP-E) is the most general problem version maximizing the line efficiency *(E)* thereby simultaneously minimizing *c* and *m* considering their interrelationship.
- Type F (SALBP-F) is a feasibility problem which is to establish whether or not a feasible line balance exists for a given combination of *m* and *c*.

(2) GALBP: In the literature, all problem types which generalize or remove some assumptions of SALBP are called generalized assembly line balancing problems (GALBP). This class of problems (including UALBP and MALBP) is very large and contains all problem extensions that might be relevant in practice including equipment selection, processing alternatives, assignment restrictions etc. (for a survey see Becker and Scholl, 2006).

- MALBP and MSP: Mixed model assembly lines produce several models of a basic product in an intermixed sequence. Besides the mixed model assembly line balancing problem (MALBP), which has to assign tasks to stations considering the different task times for the different models and find a number of stations and a cycle time as well as a line balance such that a capacity- or even cost-oriented objective is optimized (cf. Scholl, 1999, Chapter 3.2.2). However, the problem is more difficult than in the single-model case, because the station times of the different models have to be smoothed for each station (horizontal balancing; cf. Merengo et al. 1999). the better this horizontal balancing works, the better solutions are possible in the connected short-term mixed model sequencing problem (MSP). MSP has to find a sequence of all model units to be produced such that inefficiencies (work overload, line stoppage, off-line repair etc.) are minimized. (Ex. Bard et al., 1992 and Scholl et al., 1998) - UALBP: The U-line balancing problem (UALBP) considers the case of U-shaped (single product) assembly lines, where stations are arranged within a narrow U. As a consequence, worker is allowed to work on either side of the U, i.e. on early and late tasks in the production process simultaneously. Therefore, modified precedence constraints have to be observed. By analogy with SALBP, different problem types can be distinguished. (cf. Miltenburg and Wijngaard, 1994; Urban, 1998; Scholl and Klein,1999; Erel et al., 2001).

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IV. DIFFICULTIES FOR APPLICATION OF SALBP

The SALBP does not possess much applicability in real cases, and this can be verified by the difficulties that industries face to apply the theoretical models of assembly lines balancing, identified by Falkenauer [24]:

a) No balancing, but rebalancing: many studies consider that the line will still be built; however the most frequent cases areof rebalancing of existing lines.

b) Workstations have an identity: as in most cases the lines already exist, stations already have their space constraints, equipment, certain capacity of features, and restrictions of processes that can be performed.

c) Fixed operations and zoning restrictions: fixed operations can only be performed in a given station, and zoning restrictions occur when the operation can be performed at determined stations.

d) Impossibility of eliminating stations: the elimination of stations can only occur at the beginning or at the end of the existing line.

e) The need to balance the workload: after reaching the desired cycle time, the goal is to minimize the square of workload differences among stations.

f) Multiple Operators: the stations can have more than one operator simultaneously working on the product.

g) Operations of multiple operators: some activities require a second operator who helps in the process.

h) Ergonomic restrictions: the ergonomic constraints may be station or operators related.

i) Multiple products: the assembling of only one product is extremely rare.

V. HEURISTIC METHODS OF LINE BALANCING

1. Ranked Weight Method
2. Hoffmann (Precedence Matrix)
3. Immediate update first-fit (Maximum Task Time)
4. Rank and Assign (Ra) Heuristic
5. Incremental Utilization Technique
6. Largest Candidate Rule Algorithm (LCR)

Method 1: Ranked Weight Method 529 the steps involved in the (Helgeson and Birnie, 1961) positional weight method are as follows:
1) Determine the positional weight (PW) for each task (Time of the longest path from the beginning of the operation through the remainder of the network).
2) Rank the work elements based on the PW. The work element with the highest PW is ranked first.
3) Proceed to assign work elements (tasks) to the workstations, where elements of the highest positional weight and rank are assigned first
4) If at any workstation additional time remains after assignment of an operation, assign the next succeeding ranked operation to the workstation, as long as the operation does not violate the precedence relationships, and the station times do not exceed the cycle time.
5) Repeat steps 3 and 4 until all elements are assigned to the workstations.

Method 2: Hoffmann (Precedence Matrix)
Hoffmann (1963) proposed an ALB algorithm using a precedence matrix. The procedure is described below:

1) Starting with station 1, a precedence feasible list of tasks is maintained from which the combination of tasks which will minimize station idle time is found via complete enumeration.

2) These tasks are assigned to station 1; the process continues with station 2 using an updated precedence feasible list. This procedure is repeated for each station in numerical order, until all tasks have been assigned. Hoffmann uses a special zero-one precedence matrix and Vector to implement the enumeration procedure. This is a square matrix, consisting of zeros and ones, in which the rows are labelled with consecutive element numbers and the columns are labelled in the same order. Entries in the matrix are as follow.

A. If the element of row i immediately precedes the element of column j, a 1 is placed in row i, column j. All other entries are zero. (Note that only immediate, 1>>3 relationships are stated explicitly. If 1>>3>>4 a one (1) is not entered in row 1, column 4.)

B. To use this matrix in generating all the feasible permutations, each column of the matrix is summed and these sums from another row adjoined to the bottom row of the matrix. The new row in the augmented matrix is termed a "code number". Next, the diagonal of the matrix is labelled with any arbitrary value (D).

C. This first code number, K1, consists of α integers (α being the number of elements to be balanced), at least one of which is zero. The elements heading the columns, in which there are zeros in K1, are candidates for the first position in the list of feasible permutations and only those elements can be candidates.

The scheme for generating the feasible combinations and balancing the line, station by station, is as follows:

1) Search left to right in the code number for a zero.

2) Select the element which heads the column in which zero is located.

3) Subtract the element's time from the cycle time remaining.

4) If the result is positive go to step 5.

5) 4a. If the result is negative go to step 6.

6) Subtract from the code number the row corresponding to the element selected and use this result as a new code number. Go to step 6.

7) Go to step 1 and start search one element to the right of the one just selected and repeat step 1- 6 until all the columns have been examined, then go to step 7.

8) Subtract the remaining cycle time (the slack time) from the slack time of the previous combination generated (If this is the first, then subtract from the cycle time).

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9) If zero or negative go to step 4a. If positive, then this set of elements just generated becomes the new combination for this station. Go to step 10.

10) Go back one code number and go back to step 1 starting one element to the right of the element which had been selected from the code number. Repeat this procedure until the last column of the first code number has been tested; the result is that the last combination generated by step 8 is the one having the maximum elemental time for this station.

11) Replace the first code number with the last code number corresponding to the previous result. (This eliminates from further consideration the elements already selected.)

12) Repeat the previous steps until all the elements have been assigned. (Code number is entirely negative.)

Method 3: Immediate update first-fit (Maximum Task Time)

The immediate update first-fit (IUFF) heuristic was proposed by (Jackson, 1962). It depends on numerical score functions that have been proposed in the literature. The steps of the heuristic are as follows:

1) Assign a numerical score n(x) to each task x.

2) Update the set of available tasks (tasks whose immediate predecessors have been assigned).

3) Among the available tasks, assign the task with the highest numerical score to the first station in which the capacity and precedence constraints will not be violated. Go to step 2.

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Method 4: Rank And Assign (Ra) Heuristic (Maximum Backward Recursive Positional Weight)

The rank-and-assign (RA) heuristic is similar to the IUFF heuristic, with the exception that the tasks are ranked from the highest to the lowest numerical score, and assignment of tasks to stations is based on this rank. We summaries the steps of the RA heuristic as follows:

1) Assign a numerical score to each task using the functions.

2) Rank tasks from the highest to the lowest numerical score.

3) Assign tasks successively to the first station in which both the precedence and capacity constraints are met.

Method 5: Incremental Utilization Technique

The Incremental Utilization Technique simply adds tasks to a workstation in order to task precedence one at a time until utilization is 100 percent or is observed to fall. Then this procedure is repeated at the next workstations for the remaining tasks. The incremental utilization heuristic is appropriate when one or more task times are equal to or greater than the cycle time.

An important advantage of this heuristic is that it is capable if solving line-balancing problems regardless of the length of task times relative of the cycle time. Under certain circumstances, this heuristic creates the need for extra tools and equipment. If the primary focus of the analysis is to minimize the number of workstations or if the tools and equipment used in the production line are either plentiful or inexpensive, this heuristic is appropriate (Chica*et al.*, 2011).

Method 6: Largest Candidate Rule Algorithm (LCR) Known as the main aim of the Line Balance is to distribute the total workload on the assembly line as evenly as possible, despite the reality in which it is impossible to obtain a perfect line balance among the workers. It is then the role of line balance efficiency which is related to the differences in minimum rational work element time and the precedence constraints between the elements. The Largest Candidate Rule (LCR) accounts for work elements to be arranged in a descending order (with reference to the station time and work elements) to each station value which is not exceeding the allowable preceded.

A task can be done by machines of different types and also by operators of different labor types. The processing time of any task is a variable determined by the skill level and efficiency of the operator. The work is divided in such a way that each operator gets equal work load. The conceptual framework proposed and briefly summarized in the preceding section serves the purpose of demonstrating how the proposed framework would work.

VI. ILLUSTRATIVE EXAMPLE - 1

Jadhao Gears PVT LTD has been established in the year 2010. It is a medium scale industry situated in MIDC Amravati. It produces ginning machine are exported to different countries. The details of the existing assembly line for ginning machine is given in Table 4.1and 4.2 .The present production rate is 40 units per day .The company want to increase this rate .So it is decided to balance the assembly line and increase production rate.

6.1: Comparison of Three Methods

Sr No.	Parameter	Present Assembly Line	LCR Method	KWM Method	RPW Method
1	Cycle time(min)	12	10	10	10
2	Idle time	23.07	10.6	10.6	10.87
3	Line Efficiency	68.5%	82.33%	82.33%	82.33%

4	Smoothness Index	11.58	7.11	7.10	7.7
5	Production Rate per day	40units	48 units	48 units	48 units
6	Balance Delay	32	17.68	17.68	17.68
7	No of Workstation	6	6	6	6

VII. ILLUSTRATIVE EXAMPLE – 2

EICHER, Pithampur Eicher Pvt. Ltd. [1] is located at Pithampur near Indore (Madhya Pradesh) it is a manufacturing unit of Eicher trucks and busses. It was set up in 1986 and it was first commercial plant in central India spread over 83 acres of land. The company is producing variety of trucks out of these models two models are the major models for which the existing line has been set up. The cycle time for each work station is 8.10 min. The Company has well equipped modern machineries for its assembly operations. The company is having multi product mixed model assembly line for producing variety of products at the same time .The Company has large range of products like Heavy commercial vehicle (HCV), Light commercial vehicle (LCV), LCV1090, and MCV. If the product of different part family is required the set- up is changed and the assembly operation of same part family can be started.Results has been taken by applying all three methods Rank positional weight, smallest processing time, heuristic method based on CPM on the data taken from EICHER Pvt. Ltd The comparison of all methods is shown in tabular form and graphical form. Table 1.4.:- Comparison between Current Method, RPW, SPT and CPM Method.

Table 6.2:- Comparison between Current Method, RPW, SPT and CPM Method [1]

S. No	Description	Present method	RPW Method	SPT Method	CPM
1	Cycle time	8.10 min.	8.10 min.	8.10 min.	8.10 min.
2	Line efficiency	59.97%	74.96%	69.20%	74.96%
3	No. of work station	15	12	13	12
4	Smoothness index	13.6515	8.428	10.20	8.38
5	Mean absolute deviation	1.2146	1.1875	1.2592	1.1708

VIII. CONCLUSION

From the present analysis it is concluded that the efficiency of the assembly line can be improved by using heuristic method. The different heuristic methods can give better results than the present method. But if we compare the method i.e. Largest candidate rule method, killbridge wester method and Rank position weight method which is applied on Jadhao Gears PVT LTD it is found that the rank position weight method improve the efficiency from 68.58% to 82.33% and increase production rate of 40 units to 48 units. Again this method is compared with Shortest processing time method and heuristic method based on critical path method it is found that the efficiency of the assembly line is improved from 59.97% to 74.96% by applying Rank position weight method.

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